TueA03

Physics of Negative Ion Beam Formation and Extraction from the Plasma Electrode Surface in High Brightness Magnetized Plasma Sources

Gwenael Fubiani, Laurent Garrigues, and Jean-Pierre Boeuf

Université de Toulouse; UPS, INPT; LAPLACE (Laboratoire Plasma et Conversion d'Energie); 118 route de Narbonne, F-31062 Toulouse cedex 9, France
CNRS ; LAPLACE ; F-31062 Toulouse, France
Corresponding author: gwenael.fubiani@laplace.univ-tlse.fr

The origin and extent of the aberrations found in high brightness negative ion beams generated by positive ion and neutral atom impacts on the cesiated surface of the plasma electrode (which separates the ion source plasma from the particle accelerator) in negative ion sources is not well understood. High brightness negative ion beams are typically employed in a wide range of applications such as in tandem type electrostatic accelerators, cyclotrons, storage rings in synchrotrons, as a precursor to produce neutrons in the Spallation Neutron Source (SNS) or to generate high power neutral beams in magnetic fusion devices. Aberrations, which have been observed experimentally, may have critical consequences for the accelerator parts and induce both a significant loss of transmitted beam power and an increase of the beam divergence. It is consequently crucial to characterize in details the origin of the aberrations in negative ion sources. Negative ion transport properties in the vicinity of the extraction aperture are difficult to assess experimentally (most of the relevant physics occurs within a few Debye length which is sub-millimetric in typical high power ion sources) and numerical modelling is used instead to calculate the plasma characteristics in the extraction region. The vast majority of self consistent numerical models for negative ion beam extraction are based on the Particle-In-Cell (PIC) method with Monte-Carlo Collisions (MCC). The simulation domain is a zoom around a single plasma electrode aperture and one of the main difficulties is to reproduce numerically accurate plasma profiles in that area. Negative ions typically have a kinetic energy of orders of a few electron-volts and are consequently very sensitive to small variations of the plasma potential; this can easily lead to erroneous estimates for the extracted negative ion beam characteristics. Current PIC models fail to reproduce some fundamental experimental observations, which is the extraction of a negative ion beam from a plasma electrode with a flat surface around the aperture. We believe this is due to a lack of knowledge on the particle distribution functions in the extraction region. These numerical models use as input parameters the particle densities and temperatures obtained from experimental measurements alone. Doing so, the calculated depth of the virtual cathode in front of the plasma electrode greatly exceeds the negative ion kinetic energy and hence most ions are reflected back onto the electrode surface reducing consequently significantly the extracted negative ion beam current (far below measured values).

In this work, we propose a different numerical approach: the plasma parameters in the extraction region are obtained from a 3D PIC-MCC calculation of the whole ion source volume [1,2]. We model the typical working conditions of an ITER prototype Radio-Frequency (RF) tandem-type high brightness negative ion source, which corresponds to a plasma electrode positively biased with respect to the other walls of the device such that the electrode is floating (i.e., the total current collected on the latter is void). We demonstrate that for flat potential profiles in the vicinity of the plasma electrode and virtual cathodes depths of order $\Delta\phi \sim -1$V, a negative ion beam current density $j_{H-} \sim 25$ mA/cm^2 with a ~15% halo may be extracted from a hydrogen plasma with a flat electrode surface. These values are comparable to experimental measurements.

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission. Support from CEA and from the French Fédération de Recherche sur la Fusion Magnétique is acknowledged. This work was granted access to the HPC resources of CALMIP supercomputing centre under the allocation 2013-P1125.

[1] G. Fubiani et al., Physics of Plasmas **20**, 113511 (2013)
[2] G. Fubiani et al., Physics of Plasmas **21**, 073512 (2014)